Analysis of Trends, Recurrences, Severity and Frequency of Droughts using SPI: Case of OR Tambo DM, Eastern Cape in South Africa

M Nkamisa
Walter Sisulu University - Mthatha Campus: Walter Sisulu University

Simbarashe Ndhleve (ndhleve@gmail.com)
Walter Sisulu University https://orcid.org/0000-0003-0428-4824

MDV Nakin
Walter Sisulu University

A Mngeni
Walter Sisulu University

H Kabiti
Walter Sisulu University

Research

Keywords: Agricultural drought, Climate change, Hydrological drought, Meteorological Drought Monitor, Standardized Precipitation Index

Posted Date: March 22nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-293389/v1

Abstract

South Africa is susceptible to droughts. However, there is little documentation on drought occurrence in South Africa at national level and its various administrative boundaries. The study aimed to profile the hydrological drought in ORTDM from 1998–2018; computing their frequency, severity and intensity so as to show areas of high vulnerability. Data used on this study was obtained from South African Weather Services in Pretoria. Standardized Precipitation Index (SPI) was calculated using the Meteorological Drought Monitor (MDM) software computing drought frequency, severity and intensity using 3 and 6 months SPI. The results showed a wide variation in monthly precipitation throughout the year. Coastal areas receive high rainfall than inland municipalities. When recorded in descending order, the drought intensity Nyandeni shows the highest drought frequency with a percentage of 62%, Mhlontlo (58%), KSDM (57%), Ngquza Hill (55%) and Port St Johns showing the least at (52%). The hydrological drought severity frequency and duration varied between 7 days to 9 weeks. Drought intensity class exposed the annual average intensity for the 5 local municipalities represented as follows; KSDM (-0.71), PSJM (-0.99), Ngquza Hill (-0.81), Nyandeni (-0.71) and Mhlontlo (-0.62). Maximum drought intensity for the 5 local municipalities showed the following results KSDM (-2.4), PSJM (-1.8), Ngquza Hill M (-1.9), Nyandeni M (-2.8) and Mhlontlo M (-3.1). The longest drought duration across OR Tambo was experienced in 2014 and has the following durations: KSDM (3 weeks), PSJM (5 weeks), Ngquza Hill (7 weeks), Nyandeni (8 weeks) and Mhlontlo (11 weeks). ORTDM is susceptible to hydrological droughts and the extent vary across local municipalities. The results could be used as a guide to the allocation of resources for drought relief purpose in a way that seeks to prioritize drought prone areas and vulnerable municipality. The SPI could be a useful when forecasting and estimating the frequency, duration and intensity of droughts. However, emphasis should be placed on improving the quality of data as this is key in improving the quality of its outcome.

Introduction

Agriculture is an important sector in the South Africa. It has remained a significant provider of employment in the rural areas, and a major earner of foreign exchange (Bates 2014). In South Africa, economic growth in rural areas, where more than 70 percent of the population is regarded as poor but have access to abundant land, is dependent on agricultural production (Mabogunje 2015). About 70% of agricultural output is used as intermediate products in other sectors and this makes it a crucial sector with several multiplier effects on the rest of the economy (McCombie and Thirlwall 2016). Agriculture is susceptible to droughts and these droughts have multiple socioeconomic effects (Gilmore 2017 et al. 2016). The sector's interconnectedness with the larger economy cannot be overemphasized. Droughts are considered major natural hazards causing destructive impact on livelihoods, the environment as well as the economies (Carley and Christie 2017; Wilhite 2014; Alexander 2017). They have both direct and indirect socioeconomic impacts and their effects are more damaging for economies driven primarily by agriculture. The nexus between droughts and climate change, agriculture, food security and poverty reduction standout prominently in the current theoretical and empirical debates on economic

development (Gilmore 2017). Drought negatively impact agricultural production thereby affecting the four dimensions of food security that is availability, stability, access and utilization (Cheeseman 2016). Studies from many developing countries strongly concur that rural economic growth and wide-spread poverty reduction require increased production in agriculture (McGlade et al. 2019). Many concur that droughts negatively impact agricultural production and efforts to reduce poverty (Udmale 2014).

South Africa is a naturally dry country that is highly vulnerable to droughts and also a major producer of agricultural goods in Southern Africa (kelly et al. 2015). It is self-sufficient in a range of food commodities and usually produces exportable surpluses (Gilmore 2017). Southern African countries, such as Namibia, Botswana, Zimbabwe, Lesotho, Zambia and Mozambique significantly rely on agricultural imports from South Africa. Droughts has multiple effects on agriculture ranging from crop losses, lower yields in crop and livestock production, increased livestock deaths, increases in insect infestation and plant and animal diseases, damage to fish habitat, forest and range fires, land degradation and soil erosion (Pimentel et al. 2014). Furthermore, there is a compelling body of knowledge that link droughts to other epidemics like famine, diseases and land degradation globally (Adams 2014). Adams (2014) further stated that drought impact on human health through increased risk of food and water shortages, increased risk of malnutrition and higher risk of water and food borne diseases. Thus drought represents a constant threat to health, food security and livelihoods (Davies 2016). Despite being a major regional player in agriculture, droughts are regular and recurrent in South Africa (Davis and Vincent 2017). Droughts have a recurrent characteristic feature; and this is especially the case for South Africa because of its highly variable climate (Tauma et al. 2015).

South Africa's annual average rainfall is approximately 450 mm and that makes the country prone to recurrent droughts (Hirooka et al. 2019). Drought periods can be characterized from a few hours (short-term) to millennia (long-term) and there are four categories namely meteorological drought, hydrological drought, agricultural drought and socio-economic drought (Botai et al. 2016). The effects of drought are not uniform with regard to time and place as their nature is indicated by precipitation, temperature, stream flow, groundwater and reservoir levels, soil moisture and snowpack (Francis 2017). In addition, droughts are triggered by different factors and so is their frequency and intensity. One school of thought argued that some of the problems caused by drought are difficult to avoid while some are avoidable through proper planning and effective drought responses (Staupe- Delgado and Kruke 2017). Thus the need for comprehensive information aided by a comprehensive research that seeks to provide baseline information on drought cannot be overemphasized (Mwangi 2016). There is very little documentation on the incidences of drought in South Africa at national level and its various administrative boundaries that can aid proper planning. South Africa is likely to experience more frequent and severe droughts in future (Spinoni et al. 2019). It is highly probable that increased climate volatility will result in increased frequency and intensity of droughts. However, to date, very little research had been done to profile droughts in South Africa. Profiling droughts has multiple benefits including identifying the most vulnerable areas for the purpose of improving monitoring, planning, raising awareness’s and interventions. This could also help in the delineation of major areas facing drought risk for effective management plans formulation by government authorities. Therefore, this study aims to establish

baseline information on the frequency and intensity of droughts in South Africa. The general intention of this study is to comprehensively profile all the droughts that occurred in O.R Tambo District Municipality during the period between 1998 to 2018. The study specifically focuses on computing the frequency, severity and intensity of the droughts in South Africa's poorest province, Eastern Cape. This information could be used in the development of a comprehensive and flexible drought management strategy to effectively reduce the impact of future droughts.

Study Area

The O.R. Tambo District Municipality (ORTDM) occupies the eastern coastal portion of the Eastern Cape Province, South Africa. The district lies along the coastline of the Indian Ocean stretching for up to 160km (Morgan 2017). The District extends over a geographical area of 15,946.84 km² and incorporates five local municipalities, referred to by Fig. 2.1 below (Morgan 2017). OR Tambo District Municipality lies between the coordinates of 32°46'31" S and 21°23' 29" E (Mlanjeni 2014). O.R Tambo is classified as a Category C2 municipality, indicating a largely rural character and low urbanization rate. In addition to agriculture, the other economic sectors are community services, trade, finance, transport, manufacturing and construction (Null 2018). Its suitable terrain and many river valleys provides irrigable land, abundant water resources, large tracts of grazing land, suitable pasture species for stock grazing, and large numbers of stock owned by rural communities (Davies 2014). The District has the richest natural resources and the most fertile soils and favourable climatic conditions. Agricultural practices are intense although climate dependent (Thomas 2014). It has diverse vegetation types ranging from grasslands, thicket, forests and bushveld (Munn 2018). Mlanjeni (2014) notes that drought incidents negatively impact agricultural production of the O.R Tambo District and contributes to food insecurity. The OR Tambo District receives plenty of rainfall and increased humidity during summer. Winters are colder especially inland. The district's climatic conditions are moderate to high rainfall areas, mainly along its sub-tropical coast and in pockets of mountainous areas (Narloch and Bangalore 2018). The climatic conditions of O.R Tambo District are warm, temperate, predominantly frost-free conditions. O.R Tambo District enjoys a high level of annual sunshine, in summer, temperatures range from 16º to 28º Celsius while winter temperatures range from 7º to 20º C. Winter months fall between April and August while summer temperatures are usually highest between November and April (Slattery 1998). The people in the O.R Tambo District enjoy four seasons of the year namely; summer, winter, spring and autumn and they are characterised by different weather conditions ranging from hot, to cool, mild, windy and cold.

Materials And Methods

Data used on this study was obtained at South African Weather Services in Pretoria. The study employed daily, monthly and annually precipitation data gathered from the SAWS for the period 1998 to 2018 and recorded using both automatic and manual weather stations located across OR Tambo District Municipality. There are a number of weather stations in the ORTD Municipality. Before 1979, the municipality had seventeen operating weather stations to assist in weather recording and forecasting.

Advances in technology led to the addition of three automatic weather stations in O.R Tambo District Municipality. The automatic weather stations are located in Port St Johns and King Sabatha Dalindyebo municipalities, see figure 1 below. According to Mlanjeni (2014), manual weather stations are not advanced because they held a majority of disadvantages such as missing data and lacked coherence. Advances in technology and the introduction of automatic weather stations became an alternative and is a more reliable solution (Aminew et al. 2019). Table 1 below shows all the weather stations in O.R Tambo District Municipality, their spatial locations and type categorised into automatic and manual weather stations.

Table 1

Rainfall weather stations in O.R Tambo District Municipality with GPS co-ordinates

Weather station	Latitude	Longitude	Type of weather station
Mthatha prison	31˚ 34’ 59.46” S	28˚ 26’ 24.52” E	Automatic
Baziya plantation	33˚ 34’ 08.98” S	28˚ 26’ 00.61” E	Manual
Qunu plantation	31˚ 46’ 49.54” S	28˚ 37’ 24.81”E	Manual
Langeni plantation	31˚ 29’ 7.61” S	28˚ 28’ 51.95” E	Manual
Libode plantation	31˚ 32’ 4.15” S	29˚ I’ 10.33” E	Manual
Cezu plantation	31˚ 46’ 31.80” S	28˚ 43’ 44.86”E	Manual
Ngqeleni prison	31˚ 40’ 12.00”S	29˚ 1’ 40.80” E	Manual
Silaka nature reserve	31˚ 39’ 9.50” S	29˚ 39’ 9.50”E	Manual
Port St John’s	31˚ 38’ 23.27” S	29˚32’ 33.57”E	Automatic
Mhlahlane plantation	31˚ 25’ 15.73”S	28˚ 32’ 38.53”E	Manual
Ntywenka plantation	31˚ 9’ 49.92” S	28˚ 32’ 30.72” E	Manual
Bele plantation	31˚ 19’ 36.91” S	28˚ 40’ 12.28”E	Manual
Lusikisiki prison	31˚ 21’ 58.00” S	29˚ 34’ 21.28 E	Manual
Xhorha plantation	31˚58’ 15.52” S	28˚ 41’ 23.19” E	Automatic
Ntsubane forest station	31˚ 24’ 24.72” S	29˚ 41’ 48.59” E	Manual
Mkhambathi Reserve	31˚ 17’ 42.40” S	29˚ 58’ 47.57” E	Manual
Etwa Bos	30˚ 17’ 43.31”E	29˚ 50’ 17.25”E	Manual
Cengcane Bos	31˚ 00’37.75” S	28˚ 45’ 41.57,,E	Manual
Source: Google Earth			

Figure 1 below shows the map for O.R Tambo District Municipality, the local municipalities and the weather stations, both automatic and manual weather stations.

Data Analyses

Rainfall data was used to compute average annual precipitation for the period 1998 to 2018 and determining the areas the normal average precipitation. Standardized Precipitation Index (SPI) was used to compute drought frequency, severity and intensity to expose the high drought risk areas. Various indices have been developed to assess the onset, severity, frequency, intensity and end of droughts (Mahlalela et. al. 2018). The selection and application of these methods is based on the anticipated objectives, nature of the indicator, local conditions, data availability and data validity (Maza et. al. 2019; Gqwede 2018; Reta et al. 2019; Gerwin et. al. 2018). This study employed the Standard Precipitation Index (SPI) because of its popularity and ability to synthesise long term data records of precipitation. This study's rainfall data spanned over 20 years (Gerwin et.al. 2018). SPI required only precipitation values to be computed, using different periods of 1-36 months. A number of studies employed the SPI and commended the index (Sprecher 2017; Tambo et al., 2017 Fischer et. al. 2018 and Gqwede, 2018). In addition to being widely recommended, this study's choice of SPI was also influenced by the nature of the available data.

In order for the results to be precise, understandable and presentable, Meteorological Drought Monitor (MDM) software program was used to compute the SPI values for the moving average at 3 months, 6 months and at 12 months (yearly) for all the stations within ORTDM. The yearly SPI was presented graphically to show the months which ORTDM was vulnerable to droughts throughout the referenced years of study (1998-2018). The MDM output results generated the frequency, intensity of droughts, drought durations, including minimum and maximum drought time lags. MDM software was used to compute both the 3 months SPI moving average (3-SPI) and 6 months SPI moving average (6-SPI). Data used on this study was obtained at South African Weather Services in Pretoria. Standardized Precipitation Index (SPI) was used to compute drought frequency, severity and intensity to expose the high drought risk areas. MDM software was used to compute both the 3 months SPI moving average (3-SPI) and 6 months SPI moving average (6-SPI).

Interpretation of SPI

Negative SPI values represent rainfall deficit, whereas positive SPI values indicated rainfall surplus. The intensity of drought was classified according to the magnitude of negative SPI values such that the larger the negative SPI values were, the more serious the event was (Otkin et al. 2019). Table 2 below is an SPI interpretation and shows the level of wetness and dryness in the rainfall data of ORTDM. The findings and results of MDM output were interpreted using the SPI Table and these conformed to the SPI interpretation table.

Table 2

SPI interpretation table

Interpretation	Values
Extremely wet	less than 2
Very wet	1.5 to 1.99
Moderately wet	1.0 to 1.49 2.0
Near normal	-0.99- 0.99
Moderately dry	-1 to 1.49
Severely dry	-1.5 to -1.99
Extremely dry	Greater than -2
Source: (Otkin et al. 2019)	

Data analysis

Data analysis is a process of systematically applying statistical or logic techniques to illustrate, condense and recap and evaluate data (Thill 2019). In this study, graphs and tables were produced to portray findings of precipitation data obtained for the period 1998-2018. SPI used Meteorological Drought Monitor (MDM) software programme to analyse output and drought formulas developed by drought researchers to compute drought frequency and intensity (Salehnia et. al. 2018). Results and findings were presented graphically using Microsoft excel and Microsoft word was used to draw tables that presented the results in order to compare the outcomes across ORTDM. One-way analysis of variance (ANOVA) was used to compare SPI values and MDM output for all the local municipalities in ORTDM to uncover the ones that experienced most drought occurrences, level of severity, frequency and intensity and highlight the most vulnerable areas within ORTDM.

Results And Discussions

This section presents the results of precipitation and Standardised Precipitation Index (SPI) trends in O.R Tambo District Municipality for the period 1998-2018. The first part of the results is the precipitation graphs for both monthly average and yearly average precipitation for the 5 local municipalities in the ORTDM. The second section focuses on the presentation of 3 and 6 months Standardised Precipitation Index (SPI) results for OR Tambo District Municipality. The results are presented for 17 weather stations located across all the 5 local municipalities. The SPI values were further analysed to give drought severity

and drought classification information for all the municipalities. Results for drought intensity includes average drought intensity, maximum drought intensity, average drought duration, maximum drought duration and most intense drought duration per local municipality. The results also present areas that are vulnerable to both agricultural and hydrological droughts during the referenced period.

Average monthly Precipitation for ORTD Municipalities

Figure 2A-E below depict the average monthly precipitation for all the five local municipalities in OR Tambo District Municipality. KSD Municipality received its highest rainfall in summer during the months December, January and February with an average monthly precipitation was 85.6mm. The average rainfall in summer was higher than the monthly average precipitation of 70.2mm reported by Mditshwa et al. (2017) for the same municipality. June is reportedly the driest month in KSD Municipality and the presented results concur with previous finding by Mahlalela et. al. (2018). KSD Municipality has an annual average precipitation 68.8mm and this is 1.1 mm less than the annual average precipitation of OR Tambo District Municipality.

Figure 5.1B depicts the average monthly precipitation patterns of Ngquza Hill for the same period (1998 – 2018). Ngquza Hill also receives most rainfall in December, January and February and has a monthly average precipitation of 132.7 mm and an average annual precipitation of 76.2mm. Coastal areas along Indian Ocean are influenced by warm Mozambique current and as a result winters are wetter and warmer than the areas inland (Thill 2019). Ngquza Hill is a coastal municipality and it is the second of all the local Municipalities in the ORTDM that received the highest rainfall. Its average annual and average monthly precipitation was higher than the other 3 local municipalities in ORTDM except Port St John's Municipality. The average monthly precipitation for Port St Johns is 88.0mm and 89.9mm the annual average precipitation. Port St Johns winters are not as dry as the rest of the other local Municipalities in ORTDM and it receives sufficient rainfall and was not susceptible to hydrological drought. Nyandeni local Municipality and Mhlontlo's local Municipality received an average monthly precipitation 65.1mm and 64.1mm and average annual precipitation is 64.9mm and 66.5mm, respectively. They both receive extremely lower rainfall in winter. Indices used to monitor monthly trends of climate in the Eastern Cape detected that areas inland are drier and colder than coastal areas (Mahlalela et al. 2018). Mhlontlo local municipality received reduced precipitation in winter season. Mhlontlo Municipality experience its driest period in 2014 and the authorities there reported loss of livestock and reduced yields on crop production (Wambua 2019).

Monthly SPI and drought severity for OR Tambo DM

Agricultural practices in ORTDM are a primary human activity therefore, it is important to compute the 3-month SPI to reflect short and medium-term moisture conditions that are a basis to agricultural droughts. The 3 months SPI helped to detect soil moisture, groundwater and reservoir storage (Cammalleri et. al. 2019). When SPI is computed for shorter accumulation periods, in this case 3 months' period, it is used

as an indicator of reduced soil moisture and this has an important impact on agriculture and crops, especially during farming seasons. Figure 3A-E below shows the graphical representation of the 3 months SPI values distribution for all the weather station in all the five local municipalities in OR Tambo District Municipality for the period 1998-2018.

Figure 3A-E illustrates that all the five municipalities are susceptible to droughts of varying magnitude and frequency and the variation is noticeable in specific areas serviced by different weather stations. The presented graphs also show incidence of extreme to severe droughts of negative 3 months SPI values above -2.5. The incidence of both meteorological, hydrological and agricultural droughts in the district municipality is not peculiar. Despite high negative drought severity figures across all the weather stations, the presented bell curves reflect higher proportion of near normal and moderately wet conditions. This is the case for all areas as per their respective weather stations. Altın (2019) and SAWS (2018) reported similar drought patterns indicating that some parts of the country experience below-normal rainfall at varying frequency with some areas being drier than others during the same period. These results concur with a number of previous studies in the Eastern Cape and South Africa in general (Altin 2019). Mhlontlo Local Municipality is one driest inland Municipalities in ORTDM and experienced multiple droughts negatively impacting agriculture and water sources between 1998-2018 (Dotse 2019). Overall, OR Tambo District Municipality is susceptible to droughts of varying intensity and the results of the 3 months SPI across the entire district municipality confirms this. The SPI drought categories from 1998-2018 of ORTDM shows that some of the levels of hydrological droughts experienced have the potential to cause some devastating impact such as shortage of drinking water and reduced crop yields. Droughts negatively impacts river flows, dam levels, crop yields and animal life (Jimmy et al. 2019). The presented spatial analyses of drought severity, recurrence nature of droughts and the level of variance across different areas could be used as a tool for identification of the most drought prone areas and drought periods and these could assist in resource allocation for drought preparedness.

Weather stations in the same municipalities show significant differences in SPI values. This therefore implies that the quality of drought data and information could be improved by increasing the density of weather stations in an area. KSDM has the highest number of weather stations and the different in SPI values across KSD municipality shows that the same municipality can experience varying degrees of drought in one period and this should not be generalised per municipality. A similar conclusion was made by Lucinda et. al. (2019). When conducting a drought related study, it is very important to look into the weather stations and compare the findings rather than generalising. Some critically affected areas might be overlooked due to a collective description of areas and results (Forbes and St. Cyr. 2019).

Months moving average SPI for ORTDM (1998-2018)

The following section quantifies the proportion of the time each of the 5 local municipalities in ORTDM experienced drought of different categories using both 3 and 6 months SPI values. Table 3 and Table 4 shows 3 and 6 months SPI results for all the five local municipalities, respectively. The SPI results have

been tabulated according to drought severity class of moderately dry, severely dry and extremely dry categories and computed for each municipality.

Table 3

Drought severity class table for ORTDM and all its local municipalities for 3 months SPI since (1998-2018)

Drought Severity Class	KSD %	PSJ %	Ngquza Hill %	Nyandeni %	Mhlontlo %	Total %of each class in ORTDM %
Moderately Dry	53	21	3	21	33	32.7
Severely Dry	31.6	8.7	10	8.7	14	14.6
Extremely Dry	21.25	6.25	10	6.2	5.4	9.3
Total (%) of all categories drought	61.2	37	50	37	52	56.5
Source: Author's computation from MDM software output programme						

The summarised results in Table 3 above show the summarised results per municipality. The results show that all the local municipality in OR Tambo District Municipality experienced droughts of varying severity at different time proportions. KSD Municipality has the highest probability of experiencing a drought with a percentage of 61.2%, followed by Mhlontlo, Ngquza Hill and lastly PSJ and Nyandeni with equal probabilities of 37%. Using the 3 months SPI values and summing up all the drought periods when the SPI is below -1, ORTDM has a 56.5% chance of experiencing drought. Agriculture in the main economic activity in ORTDM and October, November and December are the growing months. A more than 50% chance of drought in area has important implications for livelihoods and food security in areas where agriculture is the main livelihood. The higher incidence of droughts in OR Tambo was also reported by Bae et al. (2019).

Table 4

Drought severity class table for ORTDM and all its local municipalities for 6 months moving SPI since (1998-2018)

Drought Severity Class	KSD	PSJ	Ngquza Hill	Nyandeni	Mhlontlo	Total % of each class in ORTDM
Moderately Dry	53.7%	14	25	20	47.1	40
Severely Dry	24%	7	12.5	8.3	28	22
Extremely Dry	23%	7	8.3	3	31	20
Total (%) of all categories drought	47.3.2%	28.3	29.5	48	52	62
Source: Author's computation from MDM software output programme						

In addition to results on 3 months SPI drought severity classes presented in Table 3, Table 4 above presents results of the 6 months SPI for the same municipality. Unlike the 3 months SPI results which estimated a probability of 56.5% susceptibility to droughts for OR Tambo District Municipality, the 6 months SPI estimated a probability of 62%. Thus the district is likely to experience more cumulative 6 months' droughts than 3 months' droughts. These results are in line with a study by Jimmy et al. (2019) who noted that OR Tambo DM experiences hydrological droughts that intensify into agricultural droughts in a period of 6 months. These results also confirmed reports documented by the Department of Water Affairs and Forestry (DWAF) on negative anomalies perceived in ORTDM for both on surface and subsurface water (Mditshwa et. al. 2017). A report by Bae et al. (2019) highlighted only six agricultural droughts that occurred in OR Tambo District Municipality and these occurred in 2013, 2014, 2015, 2016 and 2017 (Bae et. al. 2019). However, none of the previous studies presented drought reports according to drought severity class of moderately dry, severely dry and extremely dry categories. It is important to note that literature has vast information on droughts in the Eastern Cape and OR Tambo District Municipality as show by multiple citations above but the existing lacks some level of standardisation that can warrant comparability across both space and time. This owes to the fact that drought studies lack standardisation in terms of methodology, classification and scales used a challenge also mentioned by Masupha and Moeletsi (2017). Widespread adoption and SPI or any methodology that promotes the calculation of the probability of droughts in any area could not be overemphasised especially for drought preparedness purposes.

SPI data and analyses characterise droughts in a way that detect both the onset and cessation of drought incidents, something that other indices are unable to do (Cook 2019). It also determines drought severity, frequency and intensity of droughts and identify areas of high vulnerability. Information on average drought intensity and duration is crucial for decision making purposes. Table 5 below presents

minimum and maximum drought intensity, average drought intensity and maximum drought duration for all the five Local Municipalities in OR Tambo DM.

Table 5

Drought intensity class for ORTD local Municipalities since (1998-2018)

Drought intensity Class	KSD	PSJ	Ngquza hill	Nyandeni	Mhlontlo
Average Drought Intensity	-0.77	-0.99	-0.81	-0.71	-0.62
Maximum Drought Intensity	-2.4 in 2014 June	-1.8 2014 July	-1.9 2015 May	-2.8 2014-2015 August	-3.1 2014 June
Average Drought Duration (SPI less than -1.0 for consecutive months)	1.61	1.21	1.23	2.43	2.32
Maximum drought duration	1 month,(may 2014-June 2014)	1 month, 1 week duration (May to July 2014	1month, 2 weeks duration (May 2014-July 2014)	2 months duration May – July 2014)	2 months 2weeks duration June to September 2014.
Most intense duration (DDI (M) (SPI less than -2.0 for consecutive months)	3 weeks duration in 2014 to June 2014	5 weeks duration in 2014 (June to July 2014)	7 weeks duration (May to July 2014)	8 weeks' duration (July 2014 to September 2014	11weeks duration (May 2014 to August 2014
Source: Author's computation					

Average drought intensity ranges from -0.62 to -0.99. Ngquza Hill municipality is a coastal municipality. The 3 months SPI values for Ngquza Hill are in contrast to the known supposition and theory that coastal areas are wetter than inland areas, (Sotsha, 2013). The SPI detects the onset and end of the drought. Despite presenting a mean drought intensity that is close to normal all the local municipalities experience long periods of drought ranging from 30 days to 80 days of consecutive dry days. Mhlontlo local municipality experienced the longest drought duration of 80 days and all the municipalities experienced their longest drought duration in 2014. The results of the 2014 SPI further confirm the results by Mafongoya et al. (2019) who assert that in 2014 the whole African continent experienced its worst drought in more than 50 years with life threatening and devastating impacts. The two coastal

municipalities, PSJ and Ngquza Hill, have relatively lower average drought duration. The presented outcome confirms that Nyandeni is the driest municipality as it experiences the maximum intensity and lengthy drought duration. The results agree with previous studies which asserted that areas inland are drier than coastal areas as noted by Mackay and Gross (2019) in drought studies conducted in Australia. In South Africa, the years 2014 and 2015 were drought years and Port St Johns was among local municipalities in ORTDM that experienced water stress and reported a reduction in water levels in its water bodies and reduced crop yields in farms (Mantsho 2018).

The SPI results could be provide significant statistics that could be considered for drought monitoring, drought resources allocation and drought preparedness. When distributing drought relief aid, government departments and aid agencies should prioritise inland municipalities. In addition, these results are crucial for agricultural purpose. Accordingly, Nyandeni and Mhlontlo should be highly prioritised when it comes to agricultural drought intervention strategies such as introduction of drought tolerant plants and animals. This should be the case especially when agriculture is a key livelihood activity. The maximum drought duration for Mhlontlo, Nyandeni and KSD in ORTDM shows that these municipalities are vulnerable and high risk municipalities and the same was echoed by Dotse (2016). The findings of this study confirmed the hypothesis of this study that ORTDM is susceptible to hydrological droughts and furthermore, revealed the extent of drought effect, frequency, level of severity and intensity and detailed the areas of higher vulnerability.

Conclusion

This study analyzed the findings and results of drought incidents that occurred in ORTDM during 1998–2018. The SPI output assisted in profiling and tabulating the drought incidents of ORTDM since 1998–2018 identifying the most vulnerable drought areas in ORTDM, areas of high drought intensity and most severely affected areas in the District. Average monthly precipitation for all the five local municipalities confirms that ORTDM receives more rainfall in summer than in winter and coastal areas receive high rainfall than inland municipalities. However, there are similarities in the distributions of yearly precipitation amongst all the local municipalities. All local municipalities received high precipitation during summer during the months December, January and February; and low precipitation during winter months (May, June and July). The findings of this study confirmed the hypothesis of this study that ORTDM is susceptible to hydrological droughts and furthermore, revealed the extent of drought effect, frequency, level of severity and intensity and detailed the areas of higher vulnerability. Nyandeni is the highest drought risk area in ORTDM, followed by, Mhlontlo, King Sabatha Dalindyebo Municipality, Ngquza Hill and Port St Johns Municipality. Agricultural droughts are experienced in Nyandeni, Mhlontlo and KSDM; conversely hydrological droughts are experienced in Port St Johns and Ngquza Hill Municipality. The results could be used as a guide to the allocation of resources for drought relief purpose in a way that seeks to prioritize drought prone areas and vulnerable municipality. The SPI could be a useful tool when forecasting and estimating the frequency, duration and intensity of droughts. However, emphasis should be placed on improving the quality of data as this is key in improving the

quality of its outcome. The generated information could add value in decision making for the Department of Disaster Management in ORTDM and other relevant stakeholders.

Abbreviations

3-SPI 3 months Standardized Precipitation Index

6-SPI 6 months Standardized Precipitation Index

DD Drought Duration

Df Drought frequency

Di Drought intensity

DM District Municipality

Ds Drought severity

EC Eastern Cape Province

GDP Gross Domestic Product

GIS Geographic Information Systems

KSDLM King Sabatha Dalindyebo Municipality

LM Local Municipality

ORTDM Oliver Tambo District Municipality

PSJLM Port St John's Local Municipality

SAWS South African weather services

SPEI Standardized Evapotranspiration Index

Declarations

Availability of data and materials

Most of the data used in this study was sourced from the South African Weather Services and all the available data sources are also described in the main body of manuscript. These data sets are available from the corresponding author on request.

Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Funding

This study was made possible by the funding from South African National Research Foundation (NRF) and Department of Science and Technology (DST) through Walter Sisulu University's Risk and Vulnerability Science Centre.

Authors' contributions

M.N. is a master's student who conducted the research. S.N. and H.K. were mainly responsible for technical input, the development and writing of the article. M.D.V.N and A.M were responsible for research supervision.

Acknowledgements

We would like to acknowledge the South African Weather Services who provided the data used in this study. This study was made possible by the funding from South African National Research Foundation (NRF) and Department of Science and Innovation (DSI) through Walter Sisulu University's Risk and Vulnerability Science Centre.

References

1. Altın TB, Sarış F, Altın BN (2019) Determination of drought intensity in Seyhan and Ceyhan River Basins, Turkey, by hydrological drought analysis. Theoretical and Applied Climatology, p.1–13
2. Adams M (2014) "Sustainable Production of Nutritious Food for Humanity: Food as the Nexus Between Human Health, Environmental Resilience and Social Equity."
3. Alexander DC (2017) Natural disasters. Routledge, London
4. Bates RH (2014) Markets and states in tropical Africa: the political basis of agricultural policies, Univ of California Press
5. Botai CM, Botai JO, Dlamini LC, Zwane NS, Phaduli E (2016) Characteristics of droughts in South Africa: a case study of free state and North West Provinces. Water 8(10):439
6. Cammalleri C, Barbosa P, Vogt JV (2019) Analysing the Relationship between Multiple-Timescale SPI and GRACE Terrestrial Water Storage in the Framework of Drought Monitoring. Water, 11(8), p.1672

7. Cheeseman J (2016) Food security in the face of salinity, drought, climate change, and population growth. Halophytes for Food Security in Dry Lands, Elsevier: 111–123
8. Davies S (2016) Adaptable livelihoods: Coping with food insecurity in the Malian Sahel. Springer, TOWN
9. Davis CL, Vincent K (2017) Climate risk and vulnerability: A handbook for Southern Africa, CSIR
10. Davies KA (2014) Landowners in colonial Peru, University of Texas Press
11. Dotse LNA (2016) Exploring the relationship between water scarcity on food and nutritional security in rural households in the Nqgeleni location, Eastern Cape (Doctoral dissertation)
12. Forbes KF, Cyr OS (2019) The Challenge Posed by Space Weather to High-Voltage Electricity Flows: Evidence From Ontario, Canada, and New York State. USA Space Weather 17(12):1720–1747
13. Gerwin W, Repmann F, Galatsidas S, Vlachaki D, Gounaris N, Baumgarten W, Volkmann C, Keramitzis D, Kiourtsis F, Freese D (2018) Assessment and quantification of marginal lands for biomass production in Europe using soil-quality indicators. Soil 4(4):267–290
14. Gqwede II (2018) An assessment of the challenges faced by King Sabata Dalindyebo Local Municipality in respect of the provision of electricity services, Doctoral Dissertation submitted to Stellenbosch University
15. Gilmore EA (2017) Introduction to Special Issue: Disciplinary Perspectives on Climate Change and Conflict. Current Climate Change Reports 3(4):193–199
16. Jimmy R, Govender P, Bencherif H, Moodley M (2019) TREND-RUN model application of surface temperature and its implications for South African forestry and reforestation using local weather services data. Reforesta, (7), p.50–72
17. Lucinda M, Baez-Villaneuva OM (2019) Characterizing meteorological droughts in data scare regions using remote sensing estimates of precipitation. Extreme Hydroclimatic Events and Multivariate Hazards in a Changing Environment: A Remote Sensing Approach, p.221
18. Mafongoya P, Gubba A, Moodley V, Chapoto D, Kisten L, Phophi M (2019) Climate Change and Rapidly Evolving Pests and Diseases in Southern Africa. In: New Frontiers in Natural Resources Management in Africa. Springer, Cham, pp 41–57
19. Mlanjeni NL (2014) Identification and documentation of ethnobiological methods used by rural farmers to control stalk borers on maize in the Eastern Cape province of South Africa, University of Fort Hare
20. Morgan J (2017) Australian Tussock Grasslands. Australian Vegetation: 438
21. Mditshwa S, Hendrickse RF (2017) Coega and East London industrial development zones (IDZs): the financial and socio-economic impact of the Eastern Cape IDZs and their prospects. Public and Municipal Finance
22. Mantsho SM (2018) Effect of land restitution programme on households' food security in Limpopo Province of South Africa: a case study of Waterberg District, Doctoral dissertation submitted to the University of

23. Mackay KD, Gross CL (2019) Climate Change Threatens a Fig-Frugivore Mutualism at its Drier, Western Range Margin. In Proceedings of the Linnean Society of New South Wales (Vol. 141)
24. Mabogunje A (2015) The development process: A spatial perspective. Routledge, London
25. McCombie J, Thirlwall AP (2016) Economic growth and the balance-of-payments constraint, Springer
26. Mwangi M (2016) Diverse Drought Spatiotemporal Trends, Diverse Etic-Emic Perceptions and Knowledge: Implications for Adaptive Capacity and Resource Management for Indigenous Maasai-Pastoralism in the Rangelands of Kenya. Climate 4(2):22
27. Maza A, Gutiérrez-Portilla M, Hierro M, Villaverde J (2019) Internal Migration in Spain: Dealing with Multilateral Resistance and Nonlinearites. International Migration 57(1):75–93
28. Mahlalela PT, Blamey RC, Reason CJC (2018) Mechanisms behind early winter rainfall variability in the southwestern Cape, South Africa. Climate Dynamics, p.1–19
29. Munn AA (2018) Climatology. Routledge, London
30. McGlade J, Bankoff G, Abrahams J, Cooper-Knock SJ, Cotecchia F, Desanker P, Erian W, Gencer E, Gibson L, Girgin S, Hirsch F (2019) Global Assessment Report on Disaster Risk Reduction 2019
31. Narloch U, Bangalore M (2018) "The multifaceted relationship between environmental risks and poverty: new insights from Vietnam." 23(3), p. 298–327
32. Null J (2018) "The Idyll of the Mediterranean Climate: Where Sun and Fine Wines. Flourish" Weatherwise 71(1):18–25
33. Otkin JA, Anderson MC, Hain C, Svoboda M, Johnson D, Mueller R, Tadesse T, Wardlow B, Brown J (2016) Assessing the evolution of soil moisture and vegetation conditions during the 2012 United States flash drought. Agricultural and forest meteorology. 218:230–42
34. Otkin JA, Zhong Y, Hunt ED, Basara J, Svoboda M, Anderson MC, Hain C (2019) Assessing the evolution of soil moisture and vegetation conditions during a flash drought–flash recovery sequence over the South-Central United States. Journal of Hydrometeorology 20(3):549–562
35. Otkin JA et al (2016) Assessing the evolution of soil moisture and vegetation conditions during the 2012 United States flash drought. Agric For Meteorol 218:230–242
36. Otkin JA, Zhong Y, Hunt ED, Basara J, Svoboda M, Anderson MC, Hain C (2019) Assessing the evolution of soil moisture and vegetation conditions during a flash drought–flash recovery sequence over the south-central United States. J Hydrometeorol 20(3):549–562
37. Puri J, Aladysheva A, Iversen V, Ghorpade Y, Brück T (2017) Can rigorous impact evaluations improve humanitarian assistance? Journal of Development Effectiveness 9(4):519–542
38. Sotsha K (2013) Indicators of Household-level Vunerability to Climate Change in Three Topographically Diverse Rural Villages, Doctoral dissertation submitted to the University of Fort Hare
39. Slattery D (1998) The Australian Alps: Kosciuszko, Alpine and Namadgi National Parks, UNSW Press
40. Salehnia N, Alizadeh A, Sanaeinejad H, Bannayan M, Zarrin A, Hoogenboom G (2017) Estimation of meteorological drought indices based on AgMERRA precipitation data and station-observed precipitation data. Journal of Arid Land 9(6):797–809

41. Sprecher (2017) Enhancing resilience to climate shocks through farmer innovation: evidence from northern Ghana. Reg Environ Change 17(5):1505–1514
42. Thomas K (2014) Shadows in an African Twilight: Game Ranger–Soldier-Hunter, Retrieved from eBookPartnership.com
43. Thill JC (2019) (ed) Spatial multicriteria decision making and analysis: a geographic information sciences approach. Routledge, London
44. Tauma SG, Newete SW, Adam E, Dubula B (2015) Field spectroradiometer and simulated multispectral bands for discriminating invasive species from morphologically similar cohabitant plants. GIScience Remote Sensing 55(3):417–436
45. Udmale P (2014) Farmers perception of drought impacts, local adaptation and administrative mitigation measures in Maharashtra State, India. International Journal of Disaster Risk Reduction 10:250–269
46. Wambua RM (2019) Drought Estimation-and-Projection Using Standardized Supply-Demand-Water Index and Artificial Neural Networks for Upper Tana River Basin in Kenya. International Journal of Applied Geospatial Research (IJAGR) 10(4):11–27

Figures

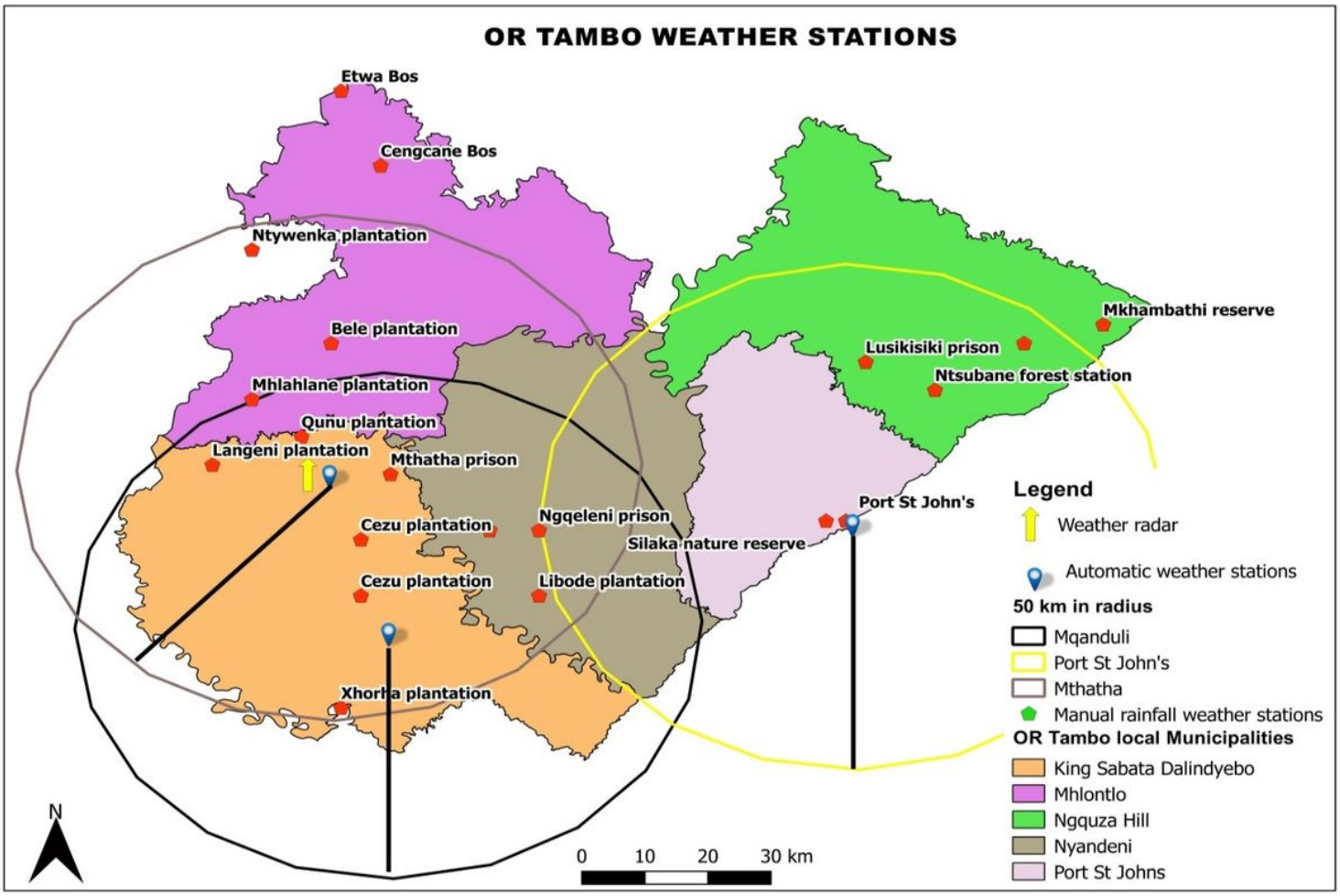

Figure 1

Distribution of Weather Stations in O.R Tambo DM Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

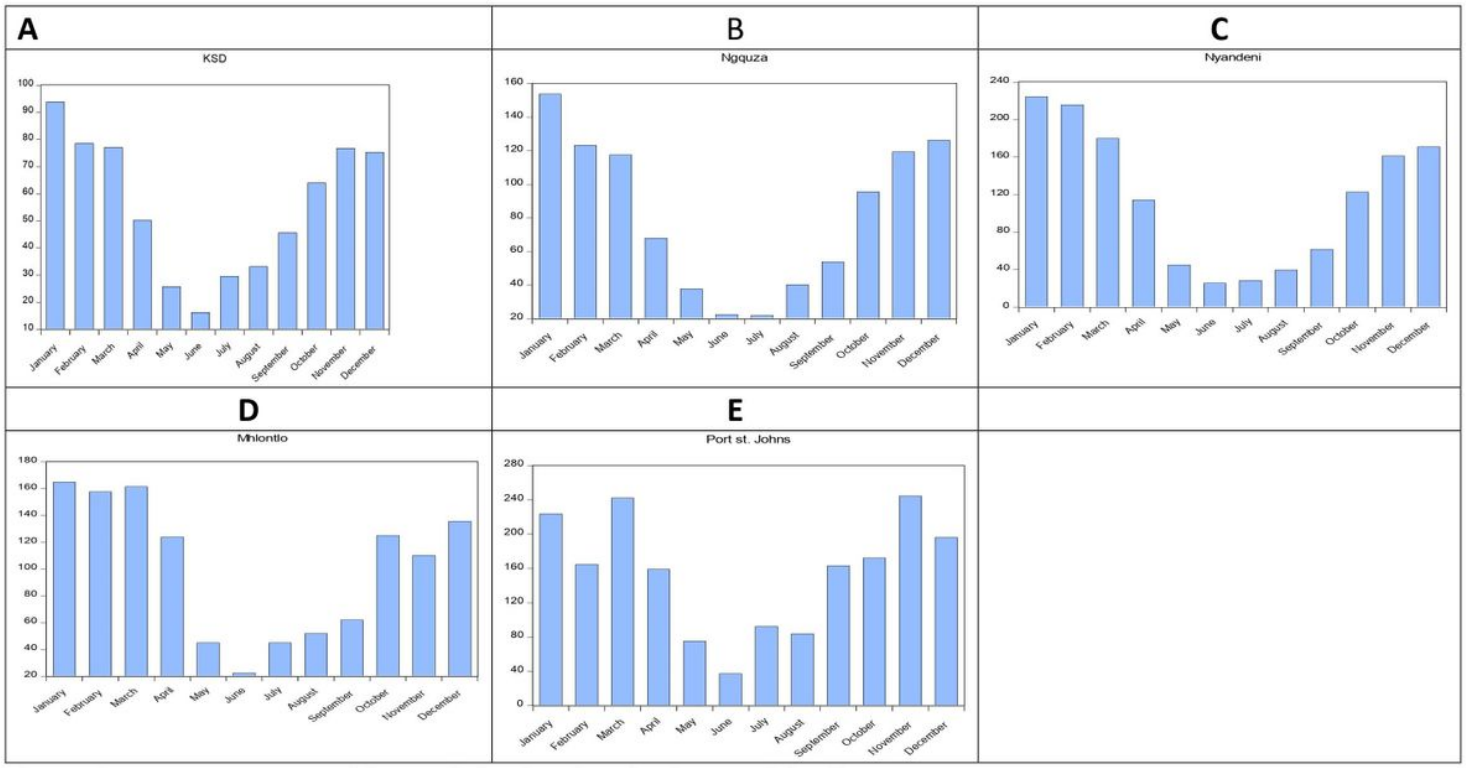

Figure 2

A-E Average Monthly Precipitation by District Municipality Source: Author's computation from data obtained from SAWS (2018)

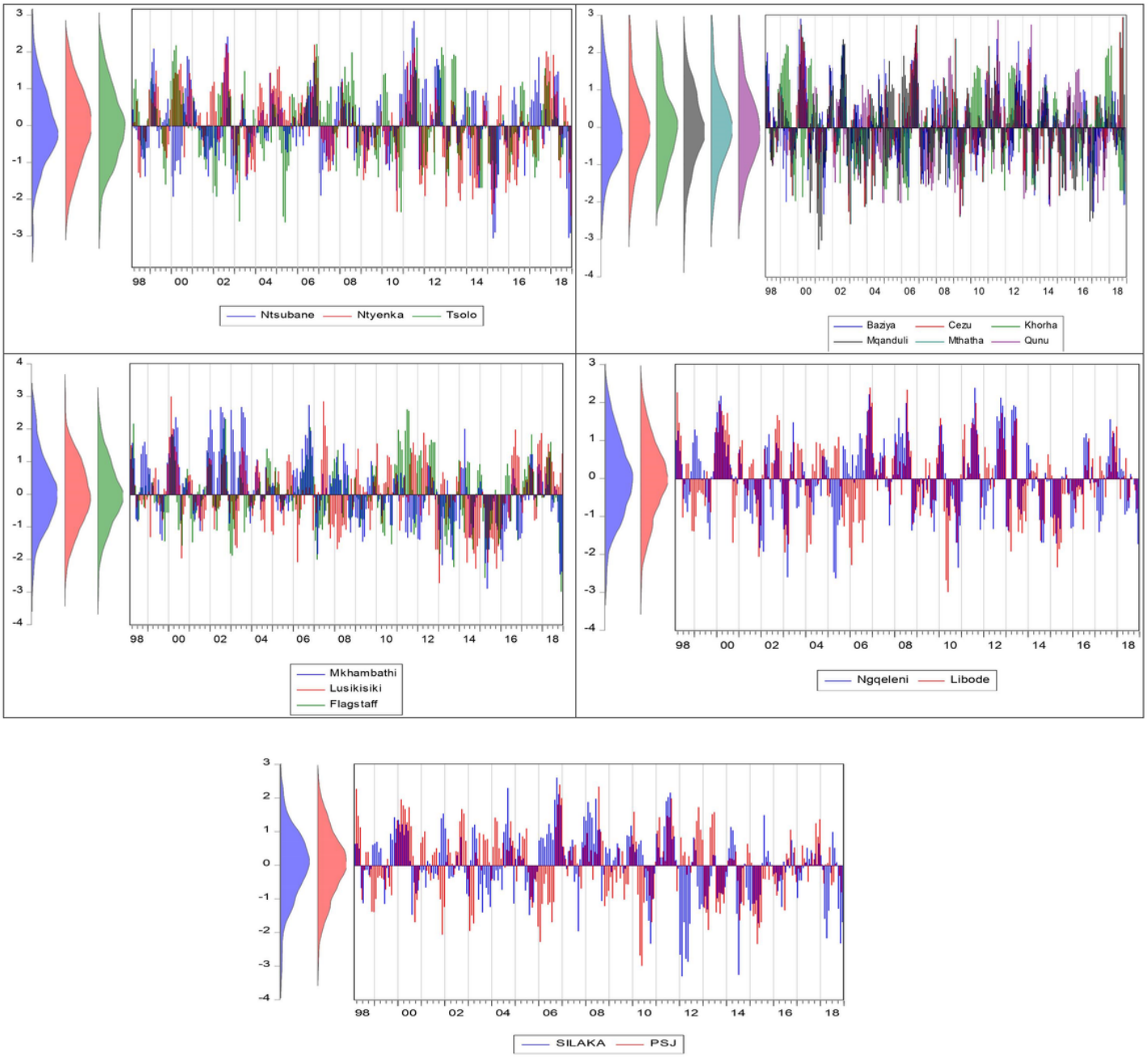

Figure 3

A-E 3 Months SPI and drought severity for OR Tambo DM Source: Author's computation from data obtained at SAWS (2018)